Day-Ahead and Short-Term Unit Commitment OPF with Voltage Stability Constraints

California ISO

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Introduction

- The California ISO (CAISO) (Folsom, CA) has developed as set of look-ahead tools with Bigwood Systems (BSI) (Ithaca, NY):
- To run analysis on forecasted operating cases to anticipate voltage problems
- To supply optimized enhancements using operational tools such as:
  - Reactive power compensating devices
  - Real generation
  - Reactive power generation
  - Load shedding to prevent collapse, worst case

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Introduction (2)

- Voltage Stability Analysis and Enhancement – Day-Ahead (VSA-DA)
- Voltage Stability Analysis and Enhancement – Short-Term Unit Commitment (VSA-STUC)
- Voltage Stability Analysis and Enhancement – Look-Ahead (VSA-LA)

Background

- Voltage instability and fluctuations tend to occur much earlier than voltage collapse
- As power systems become more stressed and the penetration of renewable energy increases, system operators need to analyze voltage security of the systems based on **actua**l operating conditions, **contingenc**y and **stressing** of the system.
- Preventive steps taken before a potential voltage collapse scenario are valuable

What is Needed?

- The ability to **anticipate problems** related to contingencies, unusual operating conditions, power transfers, etc.
- **Time** to prepare the system adjustments necessary for reliable operation of the grid
- A **longer forecast window** to provide the ISO the critical time necessary to identify voltage issues and prevent voltage collapse

Starting Points

- The ISO had in place BSI's tools using the Energy Management System (EMS) data to supply:
  - 5-minute data to On-line VSA Real-Time (VSA-RT)
  - 2-hour forecasts to On-line VSA-Look-Ahead (VSA-LA)

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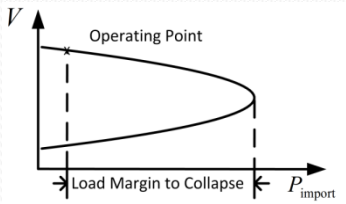
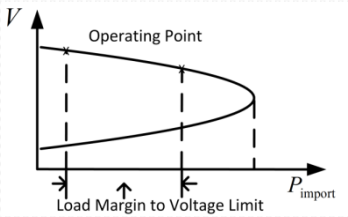
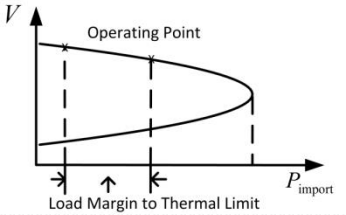
On-line VSA&E

- Comprehensive power system modeling,
- Computation of P-V curves
  - load margin to voltage collapse
  - margin to voltage limit violation
  - margin to thermal limit violation
- CIM input
- Capability curves
- Large contingency lists
- Handling of state-based RAS/SPS







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On-line VSA&E (2)

- The most advanced and patented methods are used to rapidly calculate the exact nose point and P-V, Q-V and P-Q-V curves and to perform fast contingency screening and ranking.
- When the load margin for the base case and limiting contingency is insufficient, VSA&E determines the effective preventive or enhancement control to increase load margin

Greater Reach

- The VSA&E-RT and the VSA&E-LA tools are vitally effective over the limited timeframe of the EMS source information
- To greatly expand the forecast time horizon, the ISO developed new BSI applications to supplement the EMS-based VSA&E with market-based data
- Executed on a periodic basis
- Cases developed from forecasted market postings

New Tools Introduced

- VSA-DA (24 hours ahead, hourly data)
- VSA-STUC (4.5 hours ahead, 15-minute data)
- Enhanced VSA Look-Ahead
- Employ market results to effectively supplement decision makers with a longer forecast time horizon
- Now running in production environment at the ISO

On-line Voltage Stability and Enhancement in the CAISO power market

- The day-ahead market (VSA&E-DA)
  - Processes cases for day-ahead+1 through day-ahead+6
  - Each day consists of 24 hourly cases
  - Update once per day
  - Preventive and Enhancement Control run as needed

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On-line Voltage Stability and Enhancement in the CAISO power market

- The short-term unit commitment market (VSA&E-STUC)
  - Processes cases for next 4 and one-half hours
  - Each hour consists of 4 15-minute cases
  - Updated every hour with 18 cases
  - Preventive and Enhancement Control run as needed

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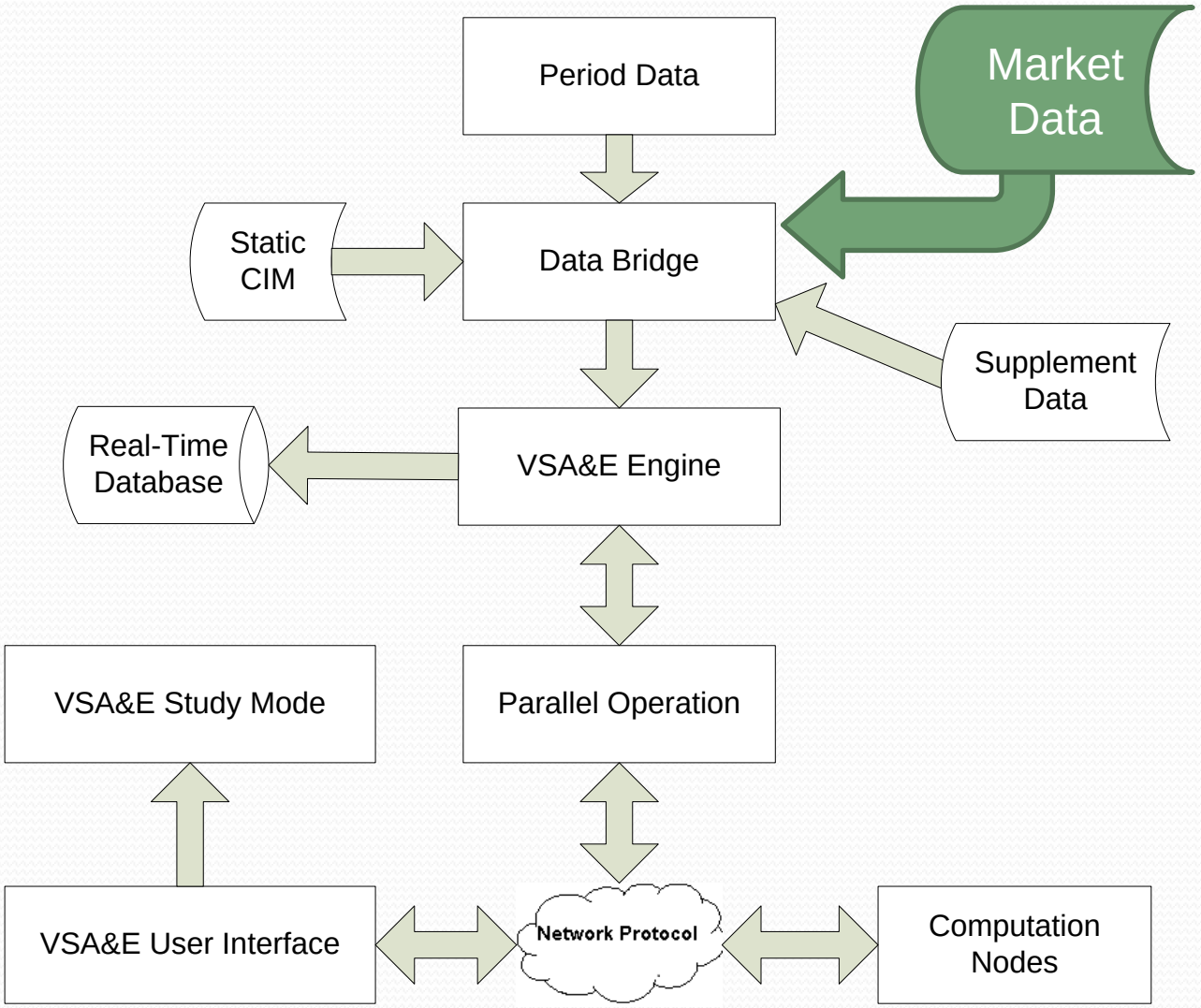
System Architecture
Distributed, High Availability



On-line VSA&E Day-Ahead and STUC

- The daily payload of Market Data and the hourly payload of Market Data are processed by VSA&E immediately on receipt
- The VSA&E model for each case is built directly using the Market data for the market areas internal to CAISO
- For market areas external to CAISO the VSA&E model is built using the EMS Static CIM database and historical data (Load Distribution Factors, Generator Distribution Factors and relevant outage information)

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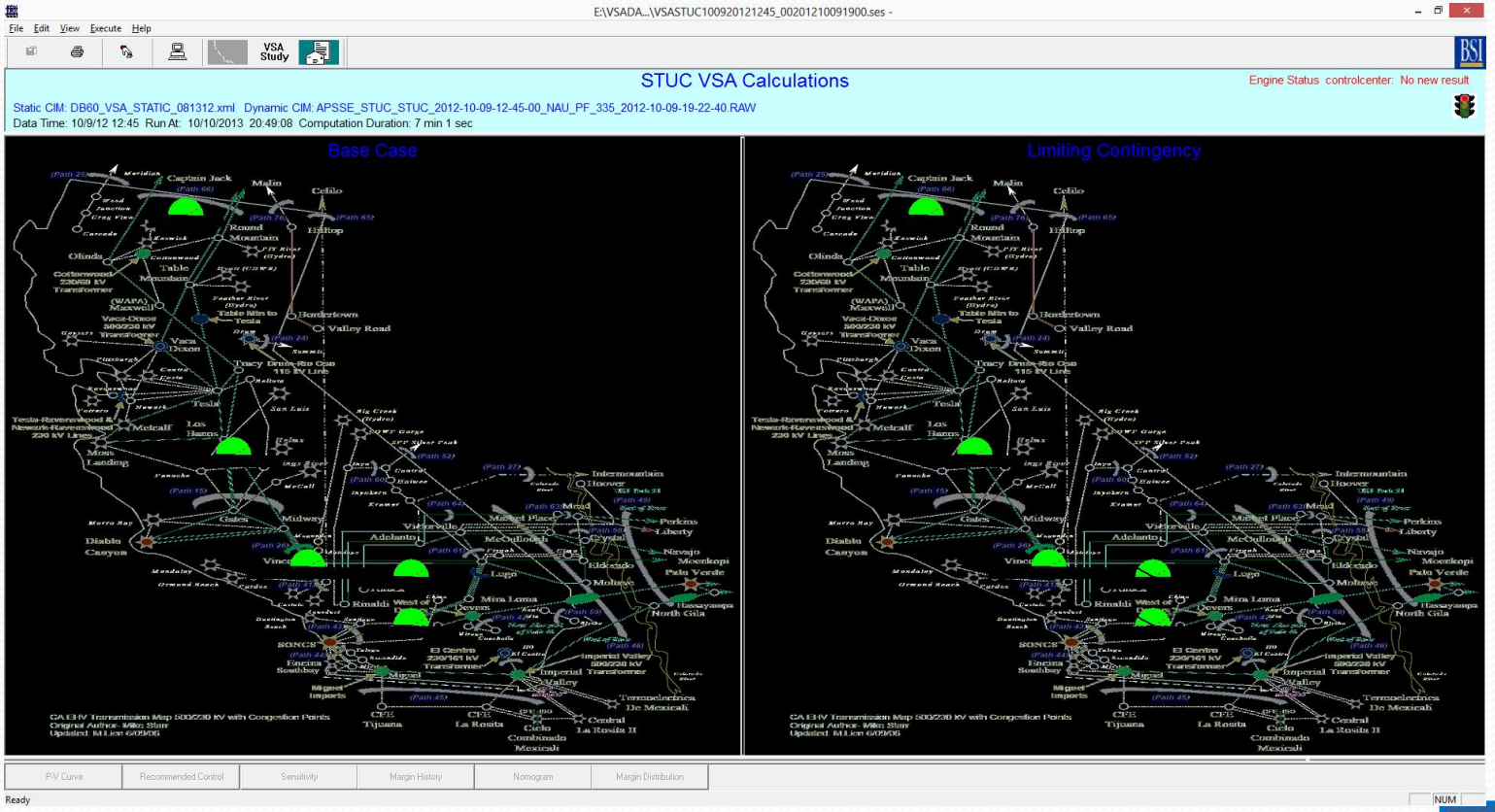
On-line VSA&E-DA-STUC Base Cases

- A base model is assembled for the entire WECC system
- BSI's power flow is run to create a base case for each time period in the batch to use in Day-Ahead Analysis and STUC Analysis
- These batched VSA&E cases and results available for display in their respective Viewer tool and for further analysis and inspection in the VSA&E Study Mode tool

On-line VSA&E User Interface



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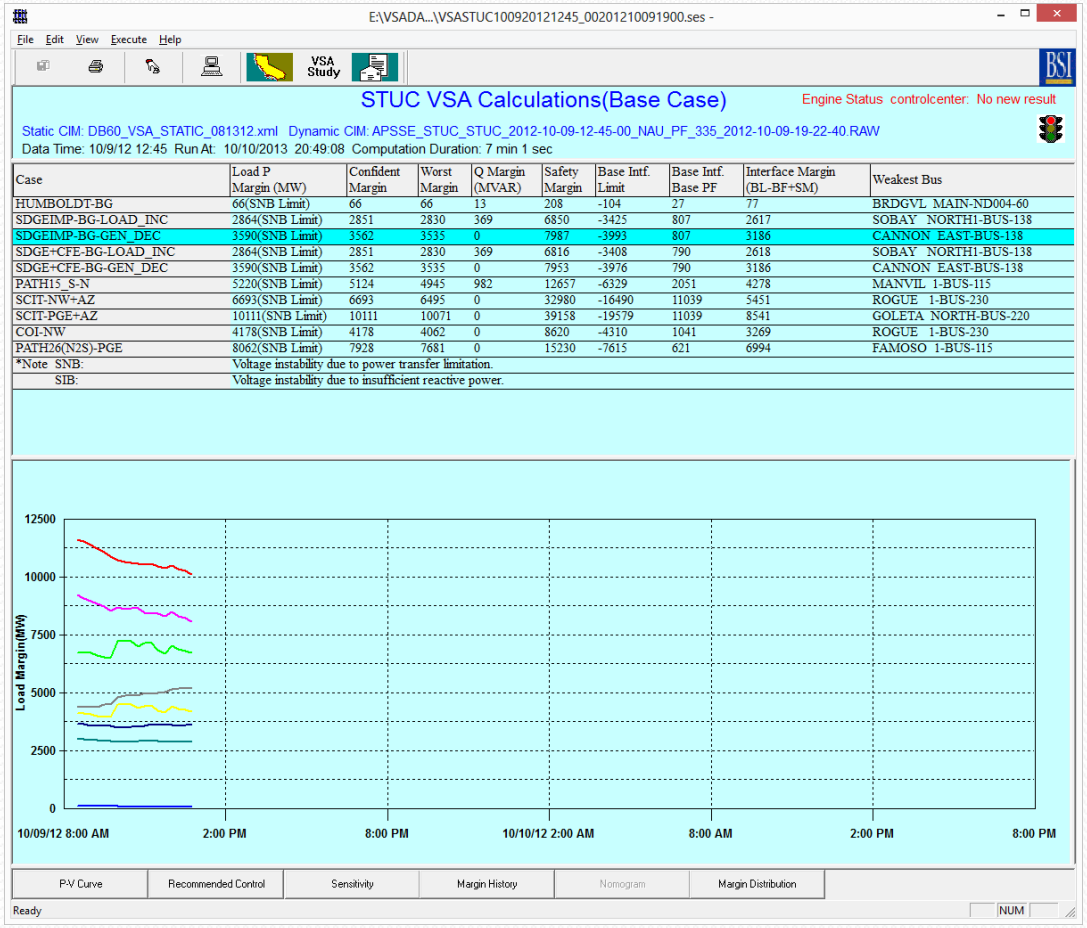
Base Case



Case	Load P Margin (MW)	Confident Margin	Worst Margin	Q Margin (MVAR)	Safety Margin	Base Intf. Limit	Base Intf. Base PF	Interface Margin (BL-BF+SM)	Weakest Bus
HUMBOLDT-BG	66(SNB Limit)	66	66	13	208	-104	27	77	BRDGVL MAIN-ND004-60
SDGEIMP-BG-LOAD_INC	2864(SNB Limit)	2851	2830	369	6850	-3425	807	2617	SOBAY NORTH1-BUS-138
SDGEIMP-BG-GEN_DEC	3590(SNB Limit)	3562	3535	0	7987	-3993	807	3186	CANNON EAST-BUS-138
SDGE+CFE-BG-LOAD_INC	2864(SNB Limit)	2851	2830	369	6816	-3408	790	2618	SOBAY NORTH1-BUS-138
SDGE+CFE-BG-GEN_DEC	3590(SNB Limit)	3562	3535	0	7953	-3976	790	3186	CANNON EAST-BUS-138
PATH15_S-N	5220(SNB Limit)	5124	4945	982	12657	-6329	2051	4278	MANVIL 1-BUS-115
SCIT-NW+AZ	6693(SNB Limit)	6693	6495	0	32980	-16490	11039	5451	ROGUE 1-BUS-230
SCIT-PGE+AZ	10111(SNB Limit)	10111	10071	0	39158	-19579	11039	8541	GOLETA NORTH-BUS-220
COI-NW	4178(SNB Limit)	4178	4062	0	8620	-4310	1041	3269	ROGUE 1-BUS-230
PATH26(N2S)-PGE	8062(SNB Limit)	7928	7681	0	15230	-7615	621	6994	FAMOSO 1-BUS-115
*Note SNB:	Voltage instability due to power transfer limitation.								
SIB:	Voltage instability due to insufficient reactive power.								

- Display On-line or
- Browser Mode data

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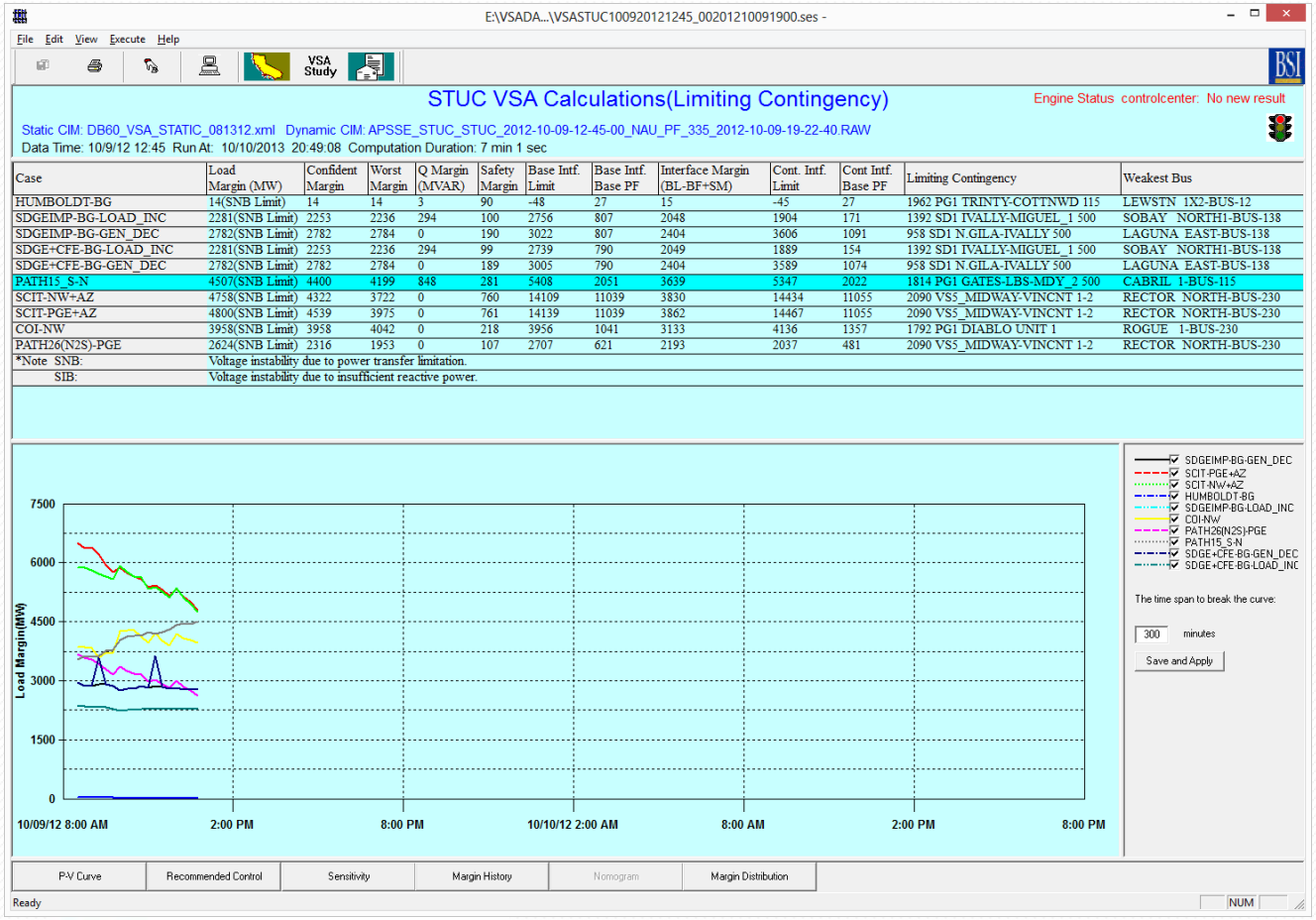
Limiting Contingency Case



Case	Load Margin (MW)	Confident Margin	Worst Margin	Q Margin (MVAR)	Safety Margin	Base Intf. Limit	Base Intf. Base PF	Interface Margin (BL-BF+SM)	Cont. Intf. Limit	Cont Intf. Base PF	Limiting Contingency	Weakest Bus
HUMBOLDT-BG	14(SNB Limit)	14	14	3	90	-48	27	15	-45	27	1962 PG1 TRINTY-COTTNWD 115	LEWSTN 1X2-BUS-12
SDGEIMP-BG-LOAD_INC	2281(SNB Limit)	2253	2236	294	100	2756	807	2048	1904	171	1392 SD1 IVALLY-MIGUEL_1 500	SOBAY NORTH1-BUS-138
SDGEIMP-BG-GEN_DEC	2782(SNB Limit)	2782	2784	0	190	3022	807	2404	3606	1091	958 SD1 N.GILA-IVALLY 500	LAGUNA EAST-BUS-138
SDGE+CFE-BG-LOAD_INC	2281(SNB Limit)	2253	2236	294	99	2739	790	2049	1889	154	1392 SD1 IVALLY-MIGUEL_1 500	SOBAY NORTH1-BUS-138
SDGE+CFE-BG-GEN_DEC	2782(SNB Limit)	2782	2784	0	189	3005	790	2404	3589	1074	958 SD1 N.GILA-IVALLY 500	LAGUNA EAST-BUS-138
PATH15_S-N	4507(SNB Limit)	4400	4199	848	281	5408	2051	3639	5347	2022	1814 PG1 GATES-LBS-MDY_2 500	CABRIL 1-BUS-115
SCIT-NW+AZ	4758(SNB Limit)	4322	3722	0	760	14109	11039	3830	14434	11055	2090 VS5_MIDWAY-VINCNT 1-2	RECTOR NORTH-BUS-230
SCIT-PGE+AZ	4800(SNB Limit)	4539	3975	0	761	14139	11039	3862	14467	11055	2090 VS5_MIDWAY-VINCNT 1-2	RECTOR NORTH-BUS-230
COI-NW	3958(SNB Limit)	3958	4042	0	218	3956	1041	3133	4136	1357	1792 PG1 DIABLO UNIT 1	ROGUE 1-BUS-230
PATH26(N2S)-PGE	2624(SNB Limit)	2316	1953	0	107	2707	621	2193	2037	481	2090 VS5_MIDWAY-VINCNT 1-2	RECTOR NORTH-BUS-230
*Note SNB:	Voltage instability due to power transfer limitation.											
SIB:	Voltage instability due to insufficient reactive power.											

- Display On-line or
- Browser Mode data

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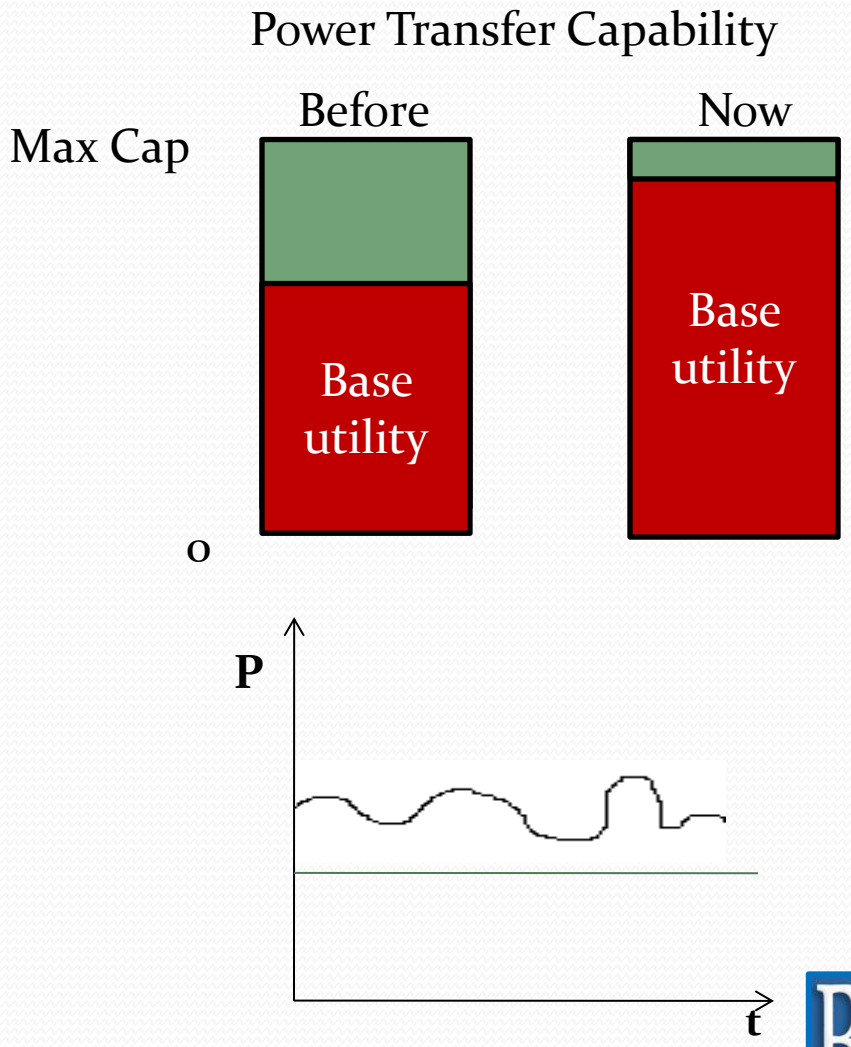
Renewable Energy Handling - Why Is it Required

- Modern Power system operates close to capacity
- Proliferation of stochastic renewable energy sources e.g. Wind & solar
- Increases uncertainty in the power system and hence possible violation of systems limitations
- No existing tools for assessing the stability of power system exposed to this danger



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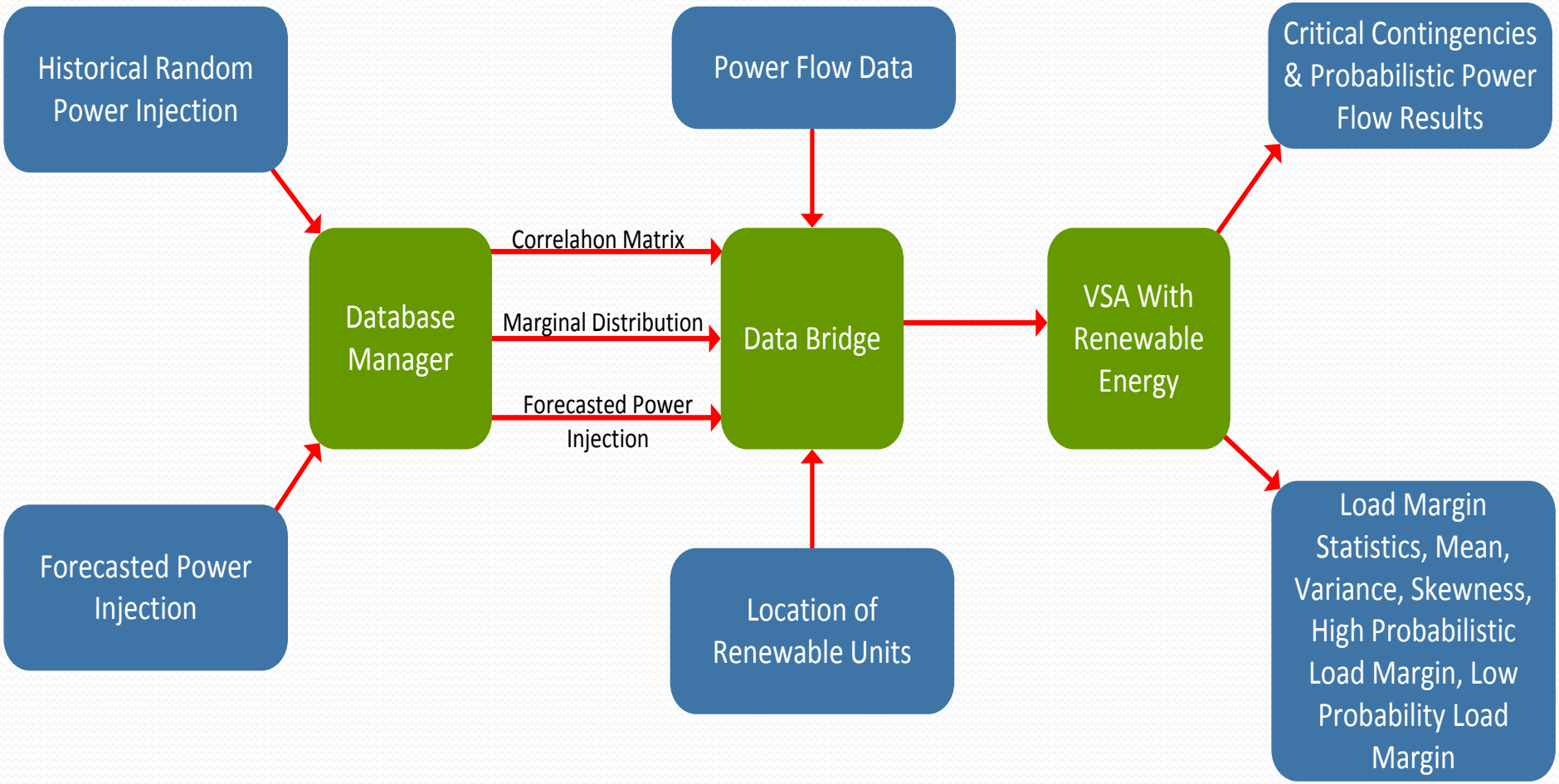
Renewable Energy Handling - How it Works



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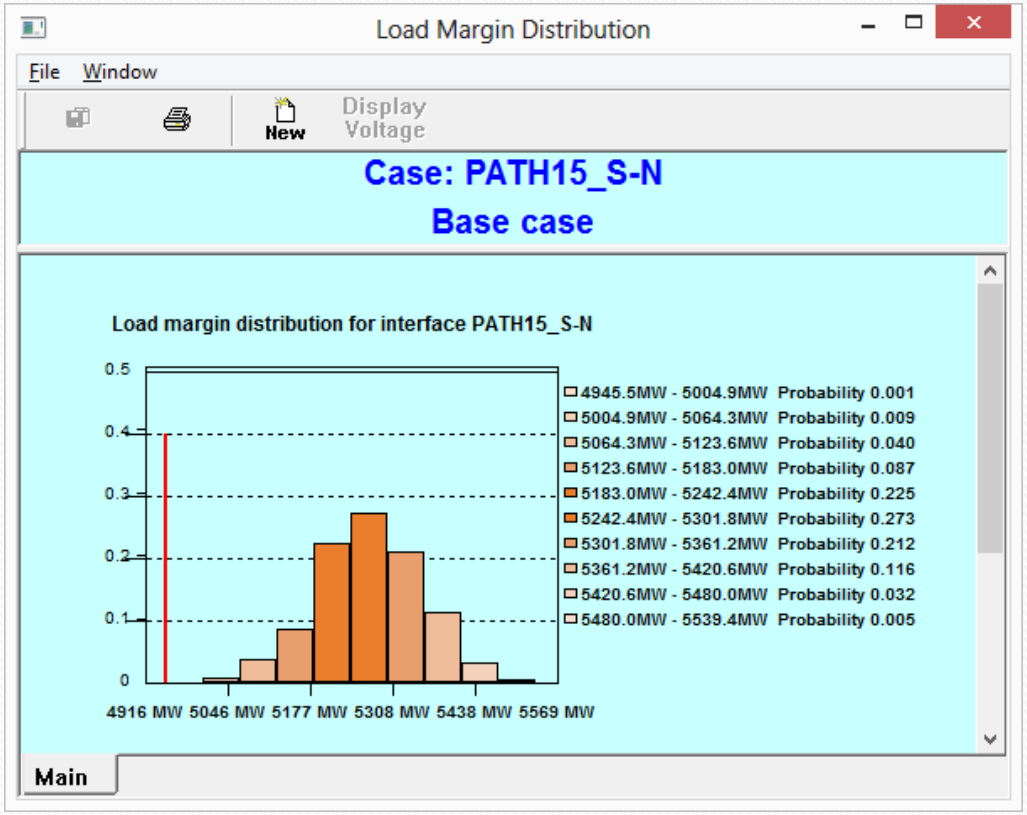
Load Margin Distribution for Renewable Scenario



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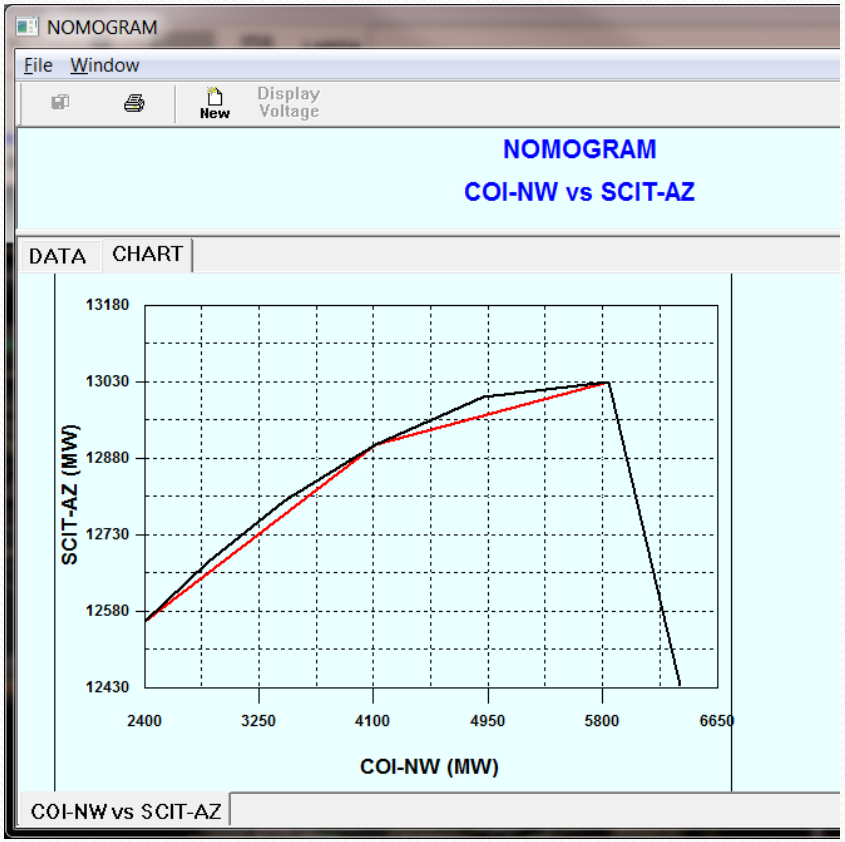
VSA&E Generated Nomogram

- Black nomogram curve represents the calculated curve
- Red nomogram curve represents the analytical representation of the nomogram.



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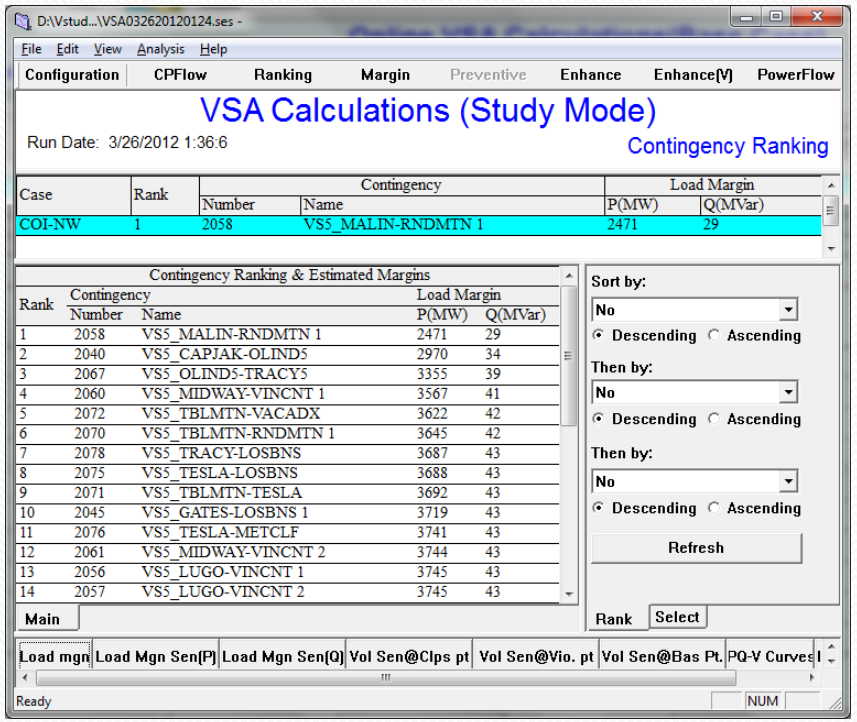
VSA&E – Study Mode

- VSA&E study tools for off-line analysis of:
  1. Current RT or LA case
  2. RT/LA/DA/STUC archived cases
  3. Imported off-line operations planning studies
  4. VSA studies built in the tool from any power flow case



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VSA&E Control

- Preventive Control for Insecure Contingencies – VSA&E determines effective preventive controls to the base case such that insecure contingencies are eliminated by exercising all available control actions before resort to load shedding.
- Enhancement Control – Determines effective enhancement controls to selected base case/contingency for desired load margins by exercising all available control actions and load shedding by applying the user design

Fast Contingency Ranking & Accurate Margin Estimation

Contingency Ranking &Estimated Margins

Session: __buildin.ses Conting. List: __buildin.ses Run Date: 6/6/06 18:00

		Contingency	Margin	
Rank	Number	Name	P	Q
1	18550	Cayuga Park-Buttermilk Mill (138/01) 138 kV line	0.000	0.000
2	18520	Hickory Hollow-Buttermilk Mill (138/02) 138 kV line	0.000	0.000
3	6820	Reuben-Quarry 115 LINE	0.000	0.000
4	18180	Taughannock#1 230/115 kV Transformer	0.000	0.000
5	18250	Applegate-Enfield & Ulysses-Swamp College	2429.753	235.050
6	18010	Ludlowville (8789) & Groton 1181	2579.699	249.556
7	6780	Van Etten-Spencer 230 LINE	2658.051	257.135
8	18730	Tioga-George-Junior 230kV & Junior Units 1,2&3	3062.834	296.293
9	18020	Virgil-Jacksonville 500 kV line & Genoa CTs	3081.472	298.096

Contingency Ranking Report showing the first 9 in the ranking, including 4 insecure, ranked 1-4

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Preventive Control Scenario

_Buildin_EAST
Preventive Control Table

Session: __buildin.ses Conting. List: __buildin.ses Run Date: 6/7/06 14:00

Preventive Control

Insecure Contingency Name	Margin for Pre-control System (MW)	Margin for Post-control System (MW)
Vanness-Bethesda-Bells Mill (13812) 138 kV line	0.000	839.510
OStreet-Bethesda-Bells Mill (13816/02) 138 kV line	0.000	1571.389
PORTLAND-PEQUEST RIVER 115 LINE	0.000	424.444
Lewistown #3 230/115 kV Transformer	0.000	2832.650

Num	Location		Area	Type	Original Amount	Control Amount	Final Amount	Upper Limit	Lower Limit
1	1105 GILBERT 230.(	1103 GILBERT 34.0kV 1	JC	LTC	1.00000	-0.08125	0.91875	1.50000	0.51000
2	1103 GILBERT 34.0	1093 GILBERT 1.0kV 1	JC	LTC	1.01910	-0.03750	0.98160	1.50000	0.51000
3	1103 GILBERT 34.0	1094 GILBERT 1.0kV 1	JC	LTC	1.01910	-0.03750	0.98160	1.50000	0.51000
4	1432 HOOVERSV 11	1433 HOOVERSV 230.0kV 1	PN	LTC	1.01510	0.11169	1.12679	1.15900	0.94970
5	1575 BELLSMIL 138.	1577 BELLSMIL 230.0kV 1	PEP	LTC	0.96700	0.16325	1.13025	1.15000	0.94090

Enhancement Control Scenario

- For user request of 200 MW, the 4 recommended control actions will enhance the load margin by 207 MW increasing the load margin from 2710 MW to 2917 MW.

_Buildin_EAST
Enhancement Control Table

Session: buildin.ses Conting. List: buildin.ses Run Date: 6/9/06 10:00

Enhancement Control

Specific Contingency Name	Steele-Vienna & Ind River- Milford
Margin for Pre-control System (MW)	2710.52002
Margin for Post-control System (MW)	2917.33008
Required Margin Increase (MW)	200.00000
Real Margin Increase (MW)	206.81000

Num	Location		Area	Type	Original Amount	Control Amount	Final Amount	Upper Limit	Lower Limit
1	1927 EDGEMOOR 2	1926 EDGEMOOR 138.0kV 1	DPL	LTC	1.00000	-0.05000	0.95000	1.05000	0.95000
2	1993 MILFORD 230	1992 MILFORD 138.0kV 1	DPL	LTC	1.00000	-0.03750	0.96250	1.50000	0.51000
3	2046 REDLION 500	2044 REDLION 230.0kV 1	DPL	LTC	1.03120	-0.00625	1.02495	1.10000	0.90000
4	1923 EDGEMOOR 19.0kV	1	DPL	Gen_Q	1.00180	0.01494	1.01674	1.05072	0.94928

CAISO VSA&E/DA/STUC: On the Drawing Board

- Renewable Energy Engine Enhancement
  - Implement Novel Scenario Generation and Reduction Schemes and Enhance Parallel Computation Engine for VSA/DA/STUC/Renewable
- Toward Reliable Solver Engines for Power Networks under Renewables: Solutions and Incorrect Data Detection
  - Improved reliable power flow solver to replace the current flat start power flow solver
- Renewable Energy: Worst Renewable Scenario
  - Computing the worst-ranked case scenarios and their associated load margins, in addition to the current confident margin, expected margin and probability distribution bar chart.

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Thank You

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